Systematic Uncertainties in Polarimetry: RHIC $\vec{p}\vec{p}$ lessons so far

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- Overview: *P* measurement & absolute normalization; polarimeters
- H-jet systematics – backgrounds (~cancel)
  - absolute scale
- pC systematics - backgrounds
  - E-scale↔A_N instability
  - C-target: dE/dz energy loss, multiple scattering θ
- Checks with data
- Future improvements (very truncated list)...

Overview

- Polarimeters measure left/right asymmetries: $\epsilon_N = (N_R - N_L)/(N_R + N_L)$
- Differences in L/R acceptances, up/down luminosities cancel using *square root formula*:

$$\epsilon_N = \frac{\sqrt{N^L_{0u} N^R_{0d}} - \sqrt{N^L_{0d} N^R_{0u}}}{\sqrt{N^L_{0u} N^R_{0d}} + \sqrt{N^L_{0d} N^R_{0u}}}$$

- Polarization↔asymmetry related by analyzing power: $P = \epsilon_N / A_N$
- Statistical uncertainty on ϵ_N
- Systematic uncertainties on ϵ_N, A_N
- A_N specific to process used (*pp* or *pC*), kinematic range (scattered E, θ)

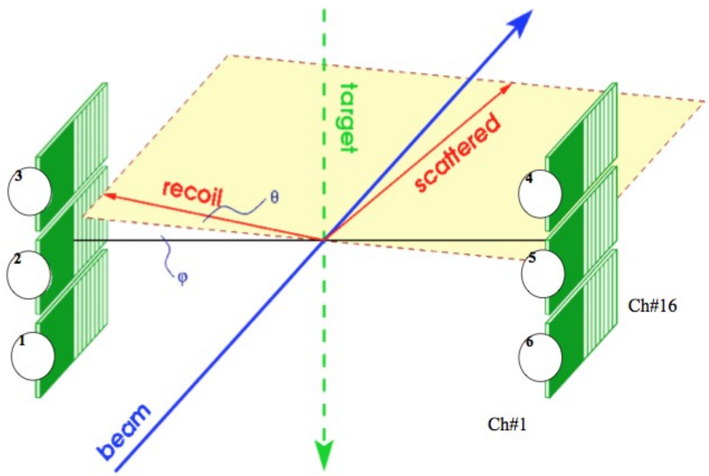
<u>Absolute normalization</u>

- H-jet (*pp* scattering) uses polarized target; provides absolute scale of beam *P*; also $A_N(pp)$. But: H-jet low statistics
- Fill-by-fill H-jet→pC: $A_N(pC) = \epsilon_N(pC)/P_{H\text{-}jet}$ normalizes pC polarimeter
- pC: high statistics, fast, transverse intensity/polarization profiles

H-jet polarimeter

Si det.:

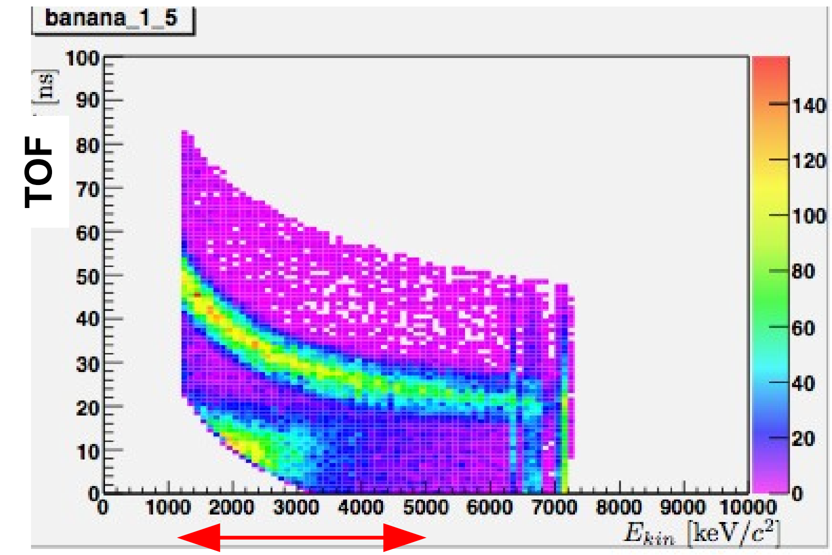
- E, TOF measure
- Long. segment. $\Rightarrow \theta_{scat}$

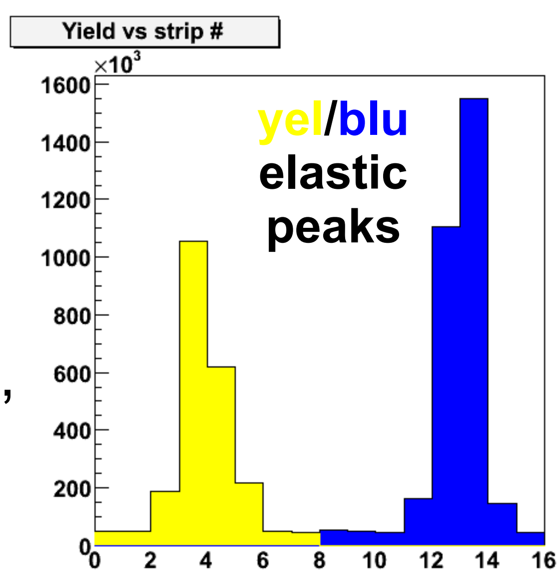


polarized H target

TOF select scattered protons: $t = \cdot\sqrt{\frac{m_p}{2E_{kin}}}$

polar. in range 1<Ep<5 MeV

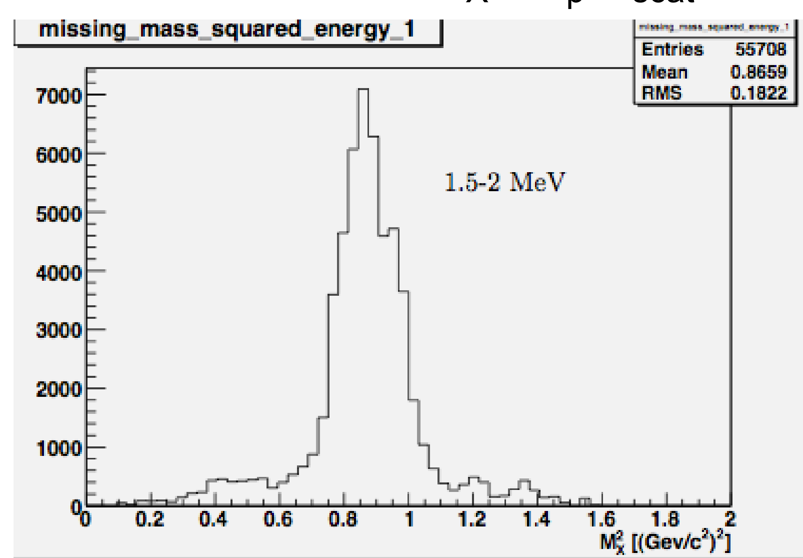




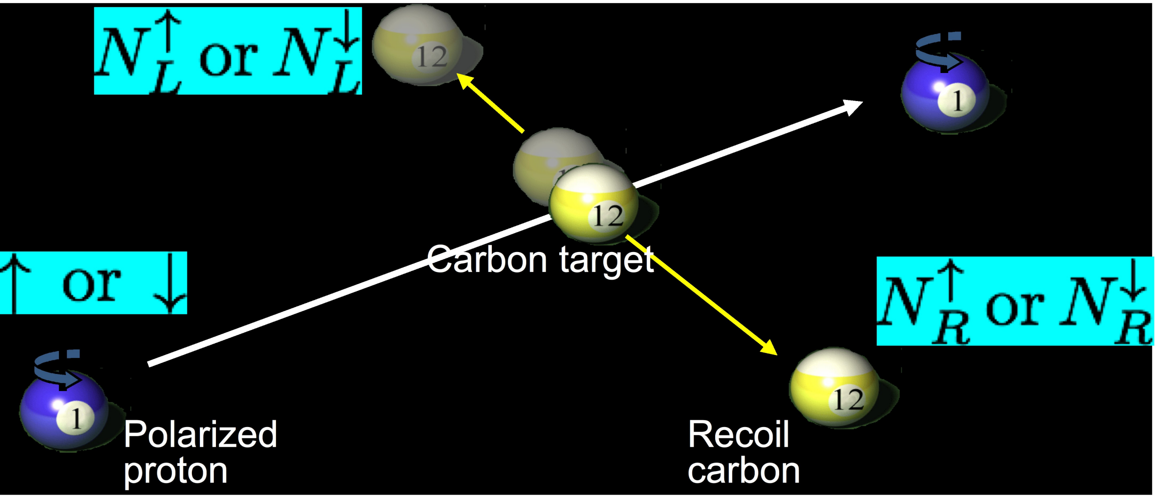
fixed Ep:

- Strip# ~ θ_{scat}
- blue forward, yellow back.

select elastic pp→pp: $M_X^2(E_p,\theta_{scat}) \approx m_p^2$

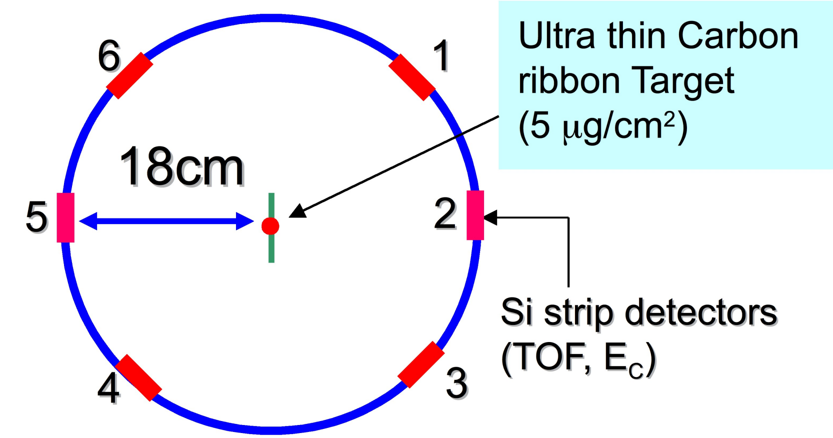


p-Carbon polarimeter



2 polarim. / RHIC ring:

beam view

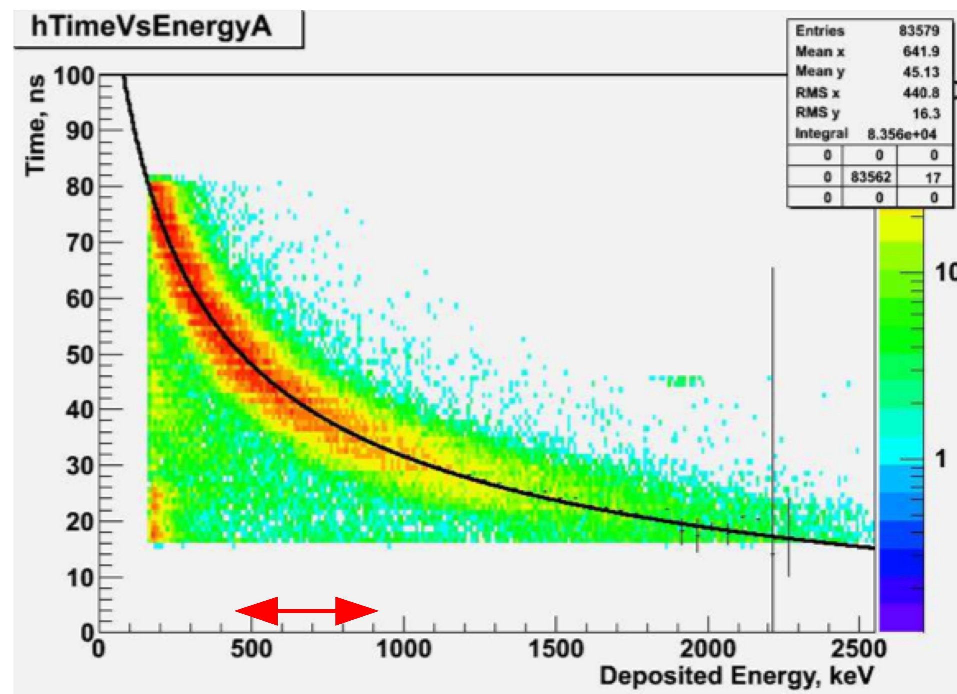


Target Scan mode (~30 sec/measurement)

- Rate 10's MHz ⇒ rel. stat. uncert. 2-3%
- 4-5 measurements per fill:

  injection, ramp before/after rotators,

  @ store every 2-3 hours
- Vertical & horizontal profiles each beam
- Normalized to H-Jet over many fills



TOF select scattered ^{12}C $0.4<E_C<0.9$ MeV

H-jet polarization

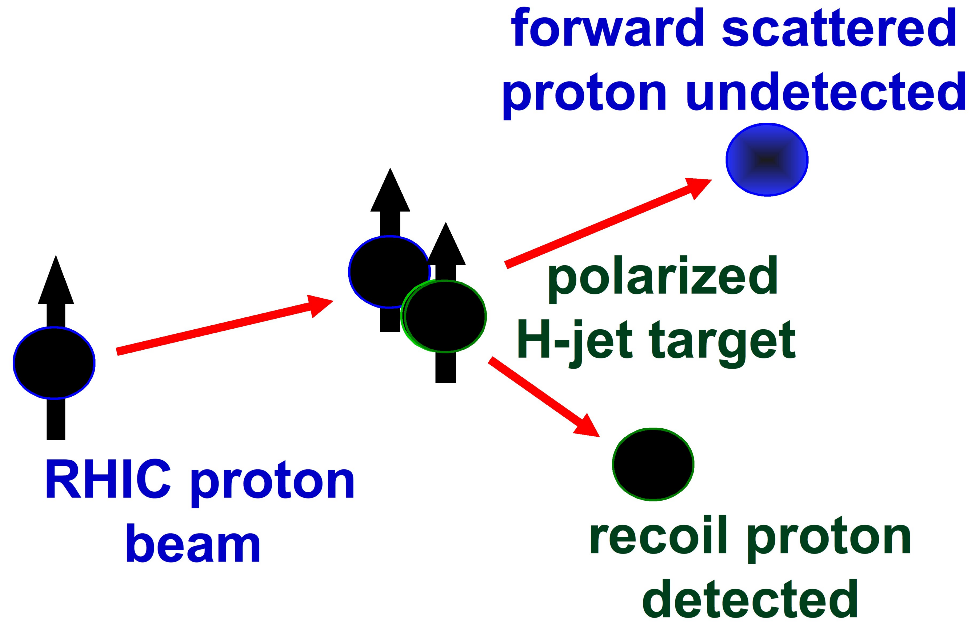
"beam", "target" identical, same A_N:

$$A_N(t) = \boxed{-\frac{\epsilon_{\text{target}}}{P_{\text{target}}}} = \boxed{\frac{\epsilon_{\text{beam}}}{P_{\text{beam}}}}$$

measured:

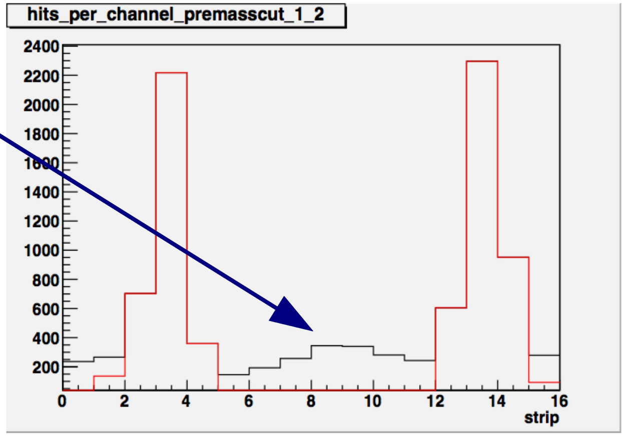
"unpol. beam" avg. ⇑ & ⇓

"unpol. target" avg. ⇑ & ⇓



- Effective A_N may vary fill-to-fill with varying background

e.g. inelastic $pp \rightarrow pp+X$:



- But: same events used for beam, target ϵ
  same bkg., effective A_N; ⇒ background ~cancels

$$\boxed{P_{\text{beam}} = -P_{\text{target}} \frac{\epsilon_{\text{beam}}}{\epsilon_{\text{target}}}}$$

P_{target} ~96% measured by Breit Rabi Polarimeter

- Uncert. Breit-Rabi ~2% (molecular H_2)
- **Overall scale uncert. *P***

pC polarization

- pC analyzing power is determined fill-by-fill from H-jet P:

  $$A_N(pC) = \epsilon_N(pC)/P_{H\text{-}jet}$$

- To reduce large statistical uncertainty from H-jet, $A_N(pC)$ each pC polarimeter averaged over set of fills
- Variations of $A_N(pC)$ each measurement, within each normalization period, introduces systematic uncertainty per measurement

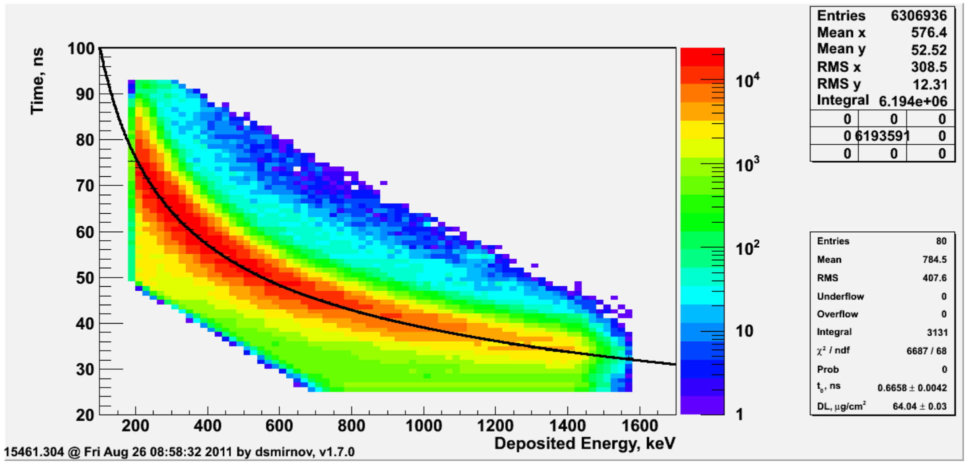
- <u>But:</u> fill-to-fill variations average out over large samples of fill, approach the limit of P scale uncertainty from H-jet

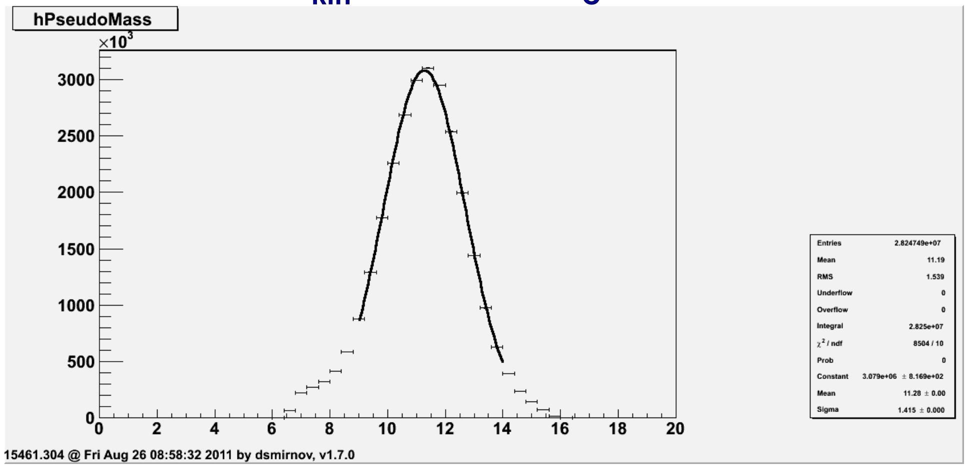
- Now consider systematic effects on $A_N(pC)$ ↘

pC backgrounds

- Backgrounds other than elastic $pC \to pC$ can change measured ϵ_N
- Equivalently: background diluted sample, different effective A_N
- e.g. background: events not in $E_{kin} \leftrightarrow$TOF 'banana':

$M(E_{kin},\mathrm{TOF}) \approx M_C$





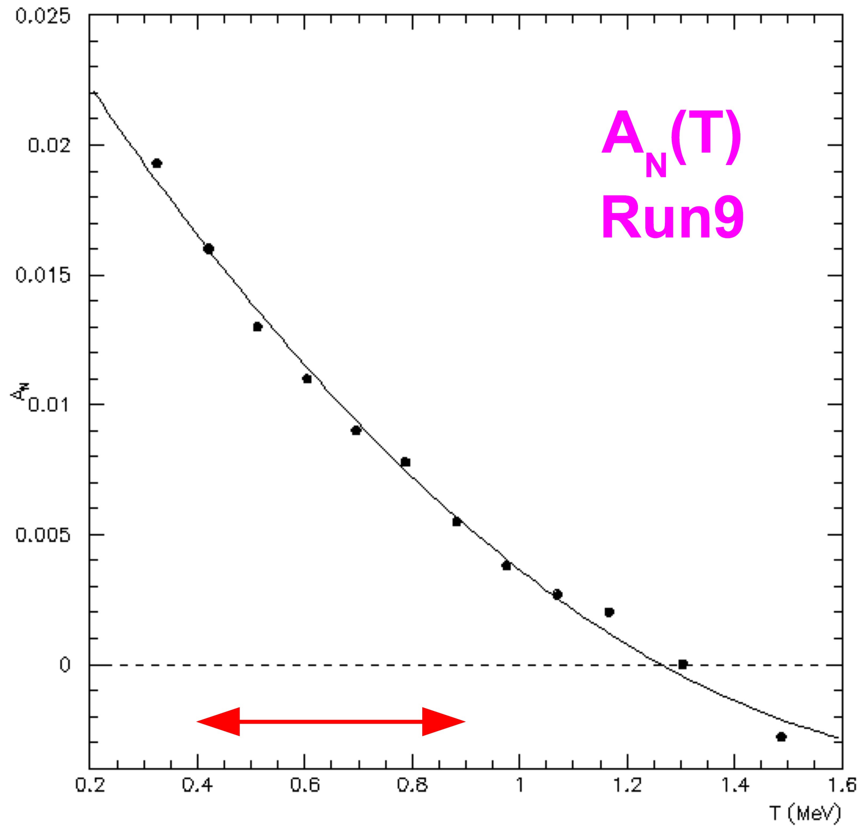
- Backgrounds small-ish, needs estimate

$A_N(pC) \leftrightarrow$ energy scale

- Analyzing power $A_N(T)$ very steep dependence on ^{12}C kinetic energy T:
- Measure in 0.4<T<0.9 MeV; effective A_N from pC/H-jet ratio
- Sensitive to ^{12}C energy scale:

e.g. $\Delta T = 25$ keV $\Rightarrow \delta A_N = 5\%$ relative

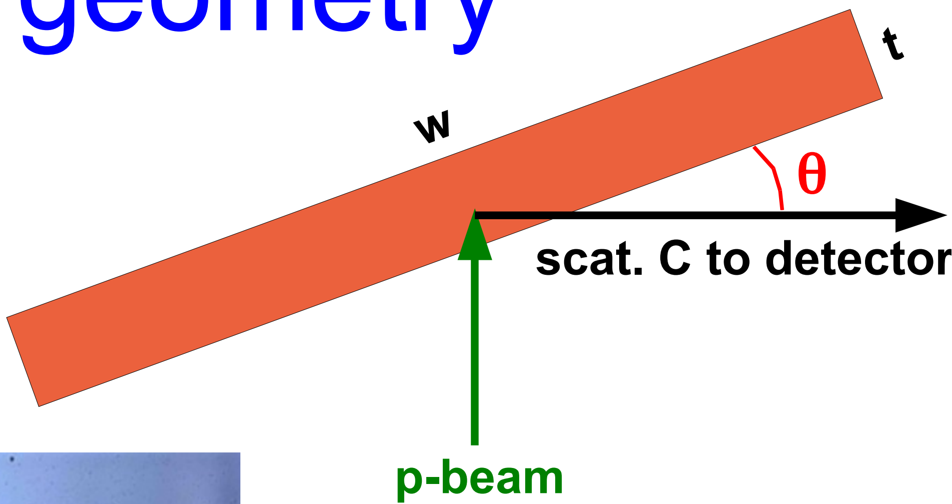
- **Energy scale of scattered ^{12}C major source of A_N, P uncertainty**



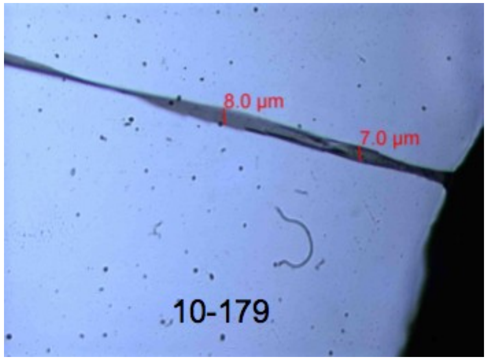
1 tick=50keV

- 1^{st} point: the energy scale uncertainty of the Si detectors introduces uncertainty on A_N, P
- e.g. estimated dead layer in Si ~60 $\mu g/cm^2$; ^{12}C in T range lose ~200 keV
- uncertainty of ~10% on dead layer $\Rightarrow$ 5% uncertainty on A_N

Ribbon target geometry



- Top view of vertical ribbon target, width $w \approx 7\mu$, thickness $t \approx 25$nm:
- Angle θ flat w-side w.r.t. detector
- Entire ribbon (w,t) is bathed in beam (beam $\sigma_{x,y}$ = 0.5-1 mm)

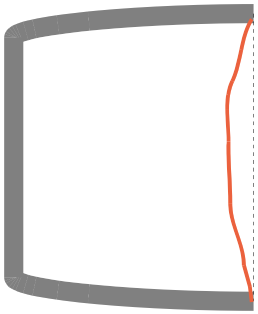


- Target may be twisted:

length scale of twists $\approx 150\ \mu$

several twists across beam

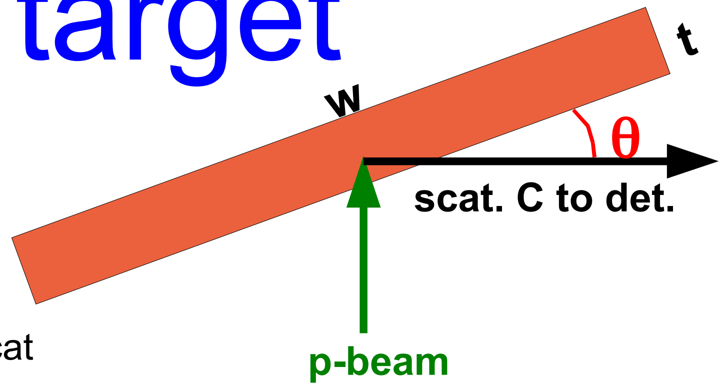
- Beam-eye view of target on frame:
- Target may be loose, up to 2-3 mm play



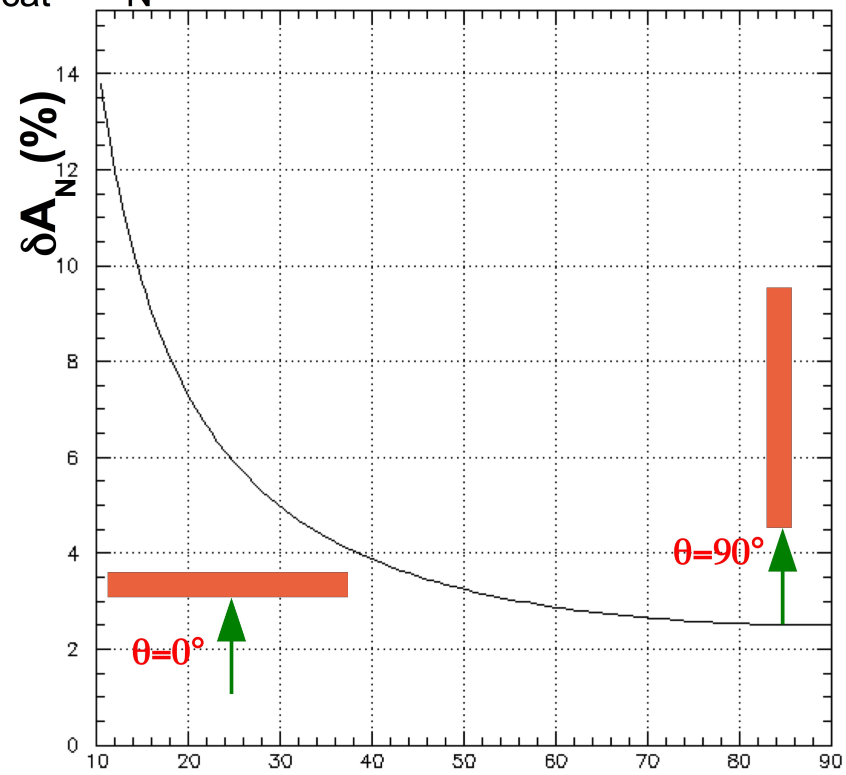
<u>As target sways in the $\vec{p}$ breeze, may:</u>

- Rotate about vertical axis, changing θ
  & path length L through target en route to detector: $L \propto t/\sin(\theta)$
- May move along beam direction, changing
  range of scattering angles covered by detector

^{12}C energy loss in target



- Scattered ^{12}C nuclei lose energy in ^{12}C target en route to Si detectors
- Measured T_{meas} down-shifted from scattered T_{scat}
- We measure over a fixed T_{meas} range
- If θ changes path length changes
  given T_{meas} corresponds to different T_{scat}, A_N:
- $L = t/(2 \cdot \sin\theta) \Rightarrow$ steep change A_N as $\rightarrow 0°$
- Put in #'s for C-C dE/dz, $A_N(T)$,
  relative variation (%) of A_N with θ:



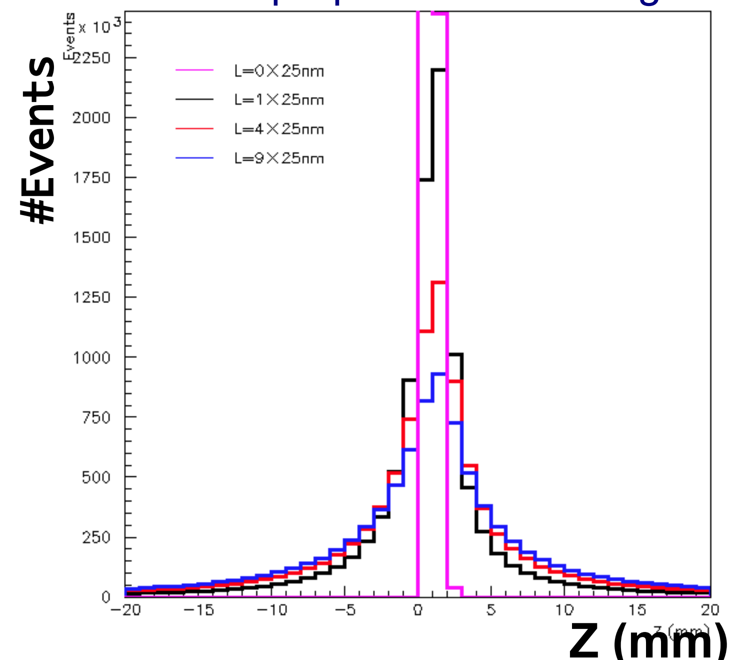
Loose targets $\Rightarrow$ unstable orientation
$\Rightarrow$ unstable effective A_N

^{12}C multiple scattering in target

- The recoil ^{12}C also undergo multiple Coulomb scattering, RMS angle $\theta_{RMS} \propto \sqrt{L/T}$ (L=path length, T=kinetic E)

- No mult. scat. ~all perpendicular to beam
- For detector 18cm from target
  more material ⇒ more events larger θ, Z:

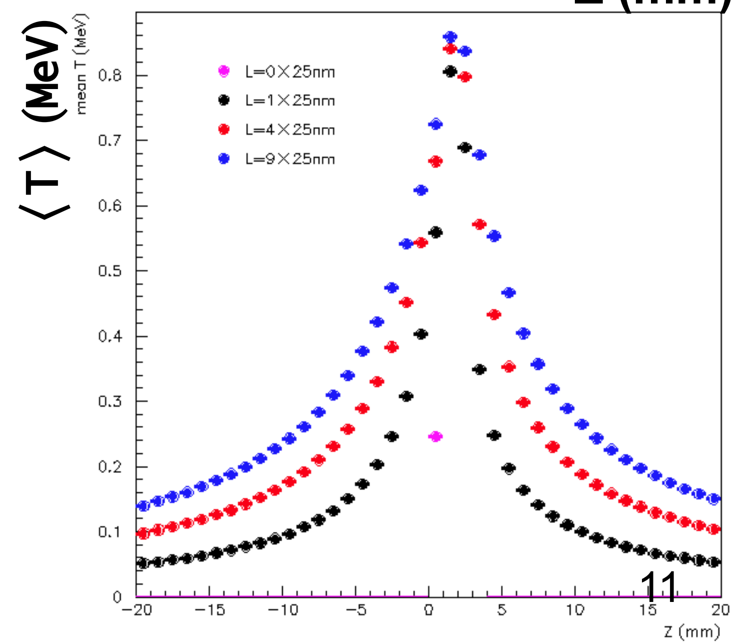
Z = direction along beam
Z = 0 perpendicular to target



- Lower energy ⇒ larger scattering angles
- Mean energy drops at larger θ, Z:

- On top of this is the energy loss in target (previous slide)

- Consider all effects ⇒ simple simulation (already used for these plots)



Simple simulation

Like RHIC pC polarimeters:

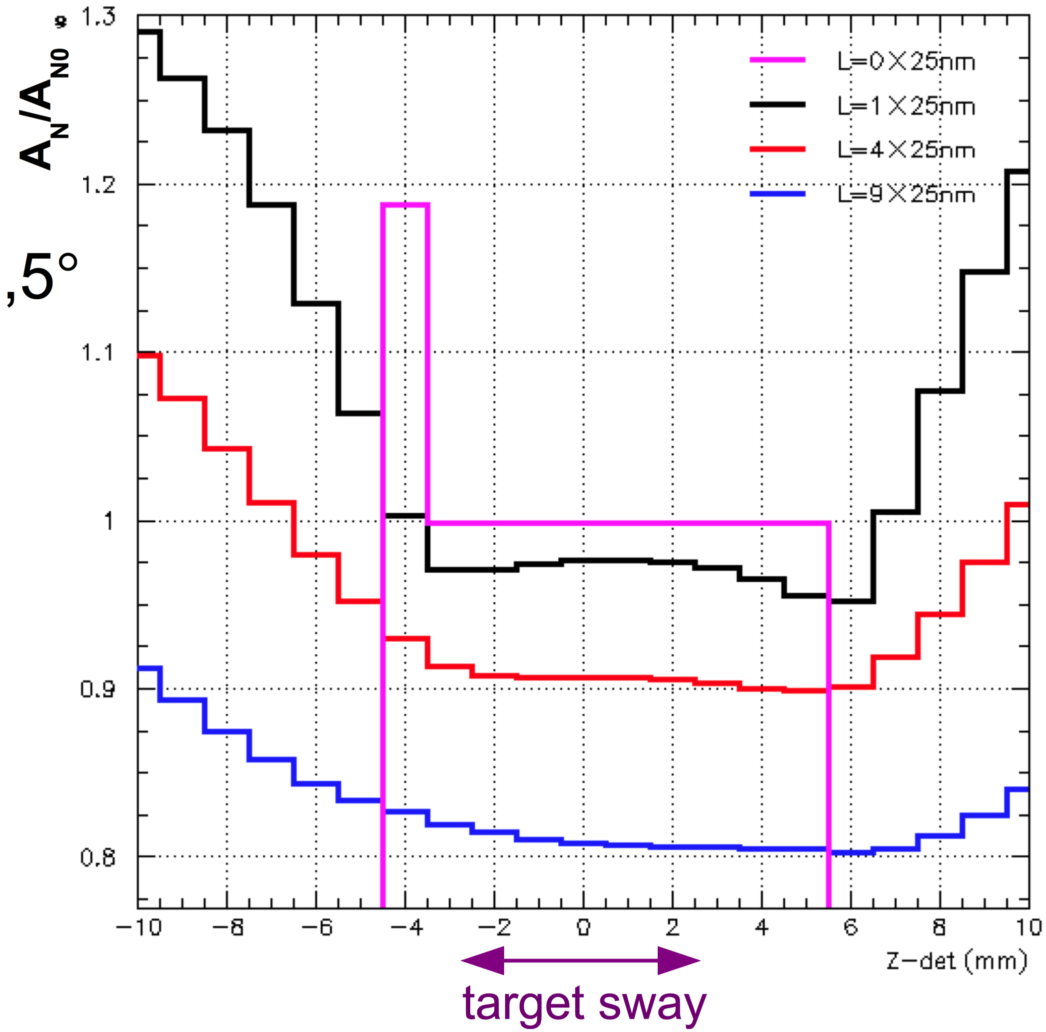
- Detector 18 cm from beam, covering 1 cm along beam axis
- Maximum paths lengths in target $L_{max}=(0,1,4,9)\times 25$ nm
- Actual path length $0<L<L_{max}$ (scattering anywhere across target)
- Multiple scattering and energy loss through L material
- After E-loss detect ^{12}C with $0.4<T_{meas}<0.9$ MeV
- For these events consider effective A_N relative to A_{N0} with no scattering, E-loss
- Look at A_N/A_{N0} as function of:
  - L_{max} (varies as target rotates about vert. axis)
  - Z = detector center along beam axis, Z=0 $\perp$ target (Z varies as target sways along beam axis)

Simple simulation

A_N/A_{N0} vs. Z-det, various L_{max}:

Z = detector center along beam
Z = 0 perpendicular to target

- 0=no material
- Rotate target about vert. axis:
  e.g. 1,4,9 = nominal target 90°,15°,5°
  4,9 = 2× thick. target 30°,15°
  4,9 = 4× thick. target 90°,45°
- As target rotates, thickness varies
  A_N can change by >15%
- As target sways longitudinally (Z-det varies), few % shifts if target-detector ~centered; much worse if misaligned

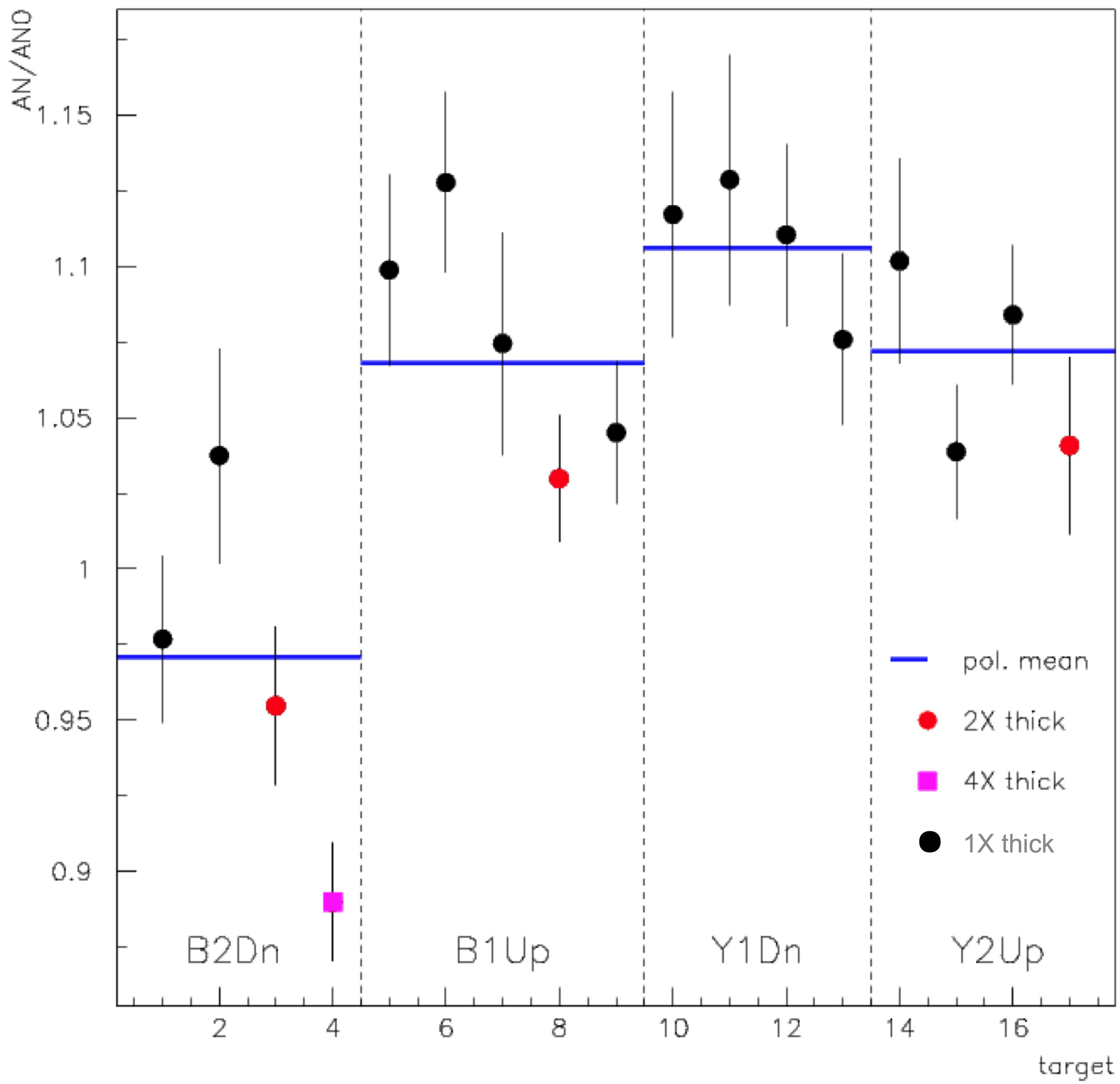


⇒ Target orientation, alignment significant effect on A_N

that was just a simulation, we have some data ➘

Data: A_N per pC target

- Run11 had nominal 25 nm thick targets, & a few 2×,4× thick.
- A_N each target determined from pC/H-jet normalization
- Relative to fixed A_{N0} (error bars statistical):



- Blue lines are mean A_N each polar.

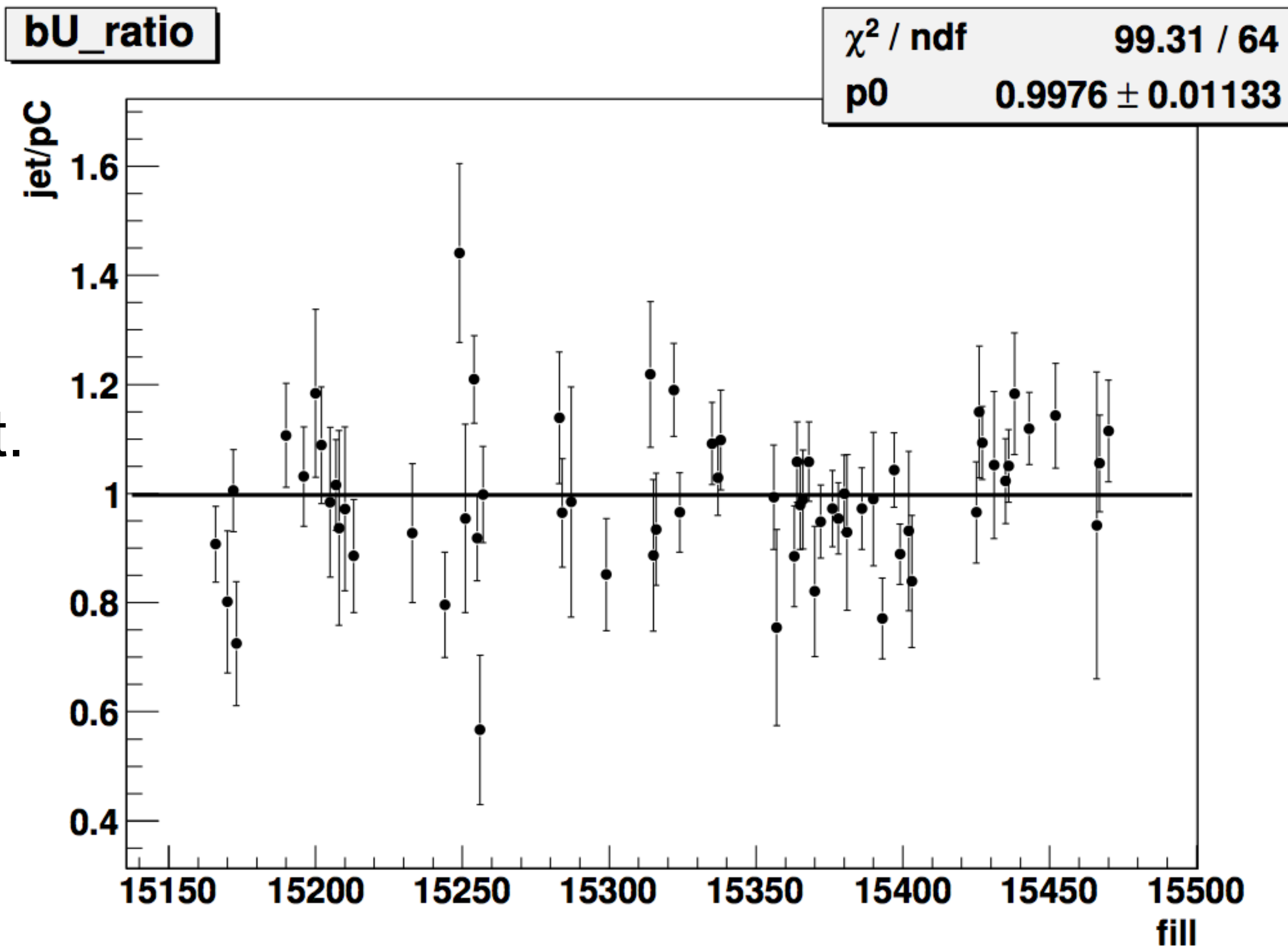
<u>Clear trend:</u>

- Thick targets lower A_N
- Consistent with more E-loss in target, lower A_N
- 1×→4× consistent with previous slide

⇒ Target thickness significant effect on A_N

Syst. checks with data

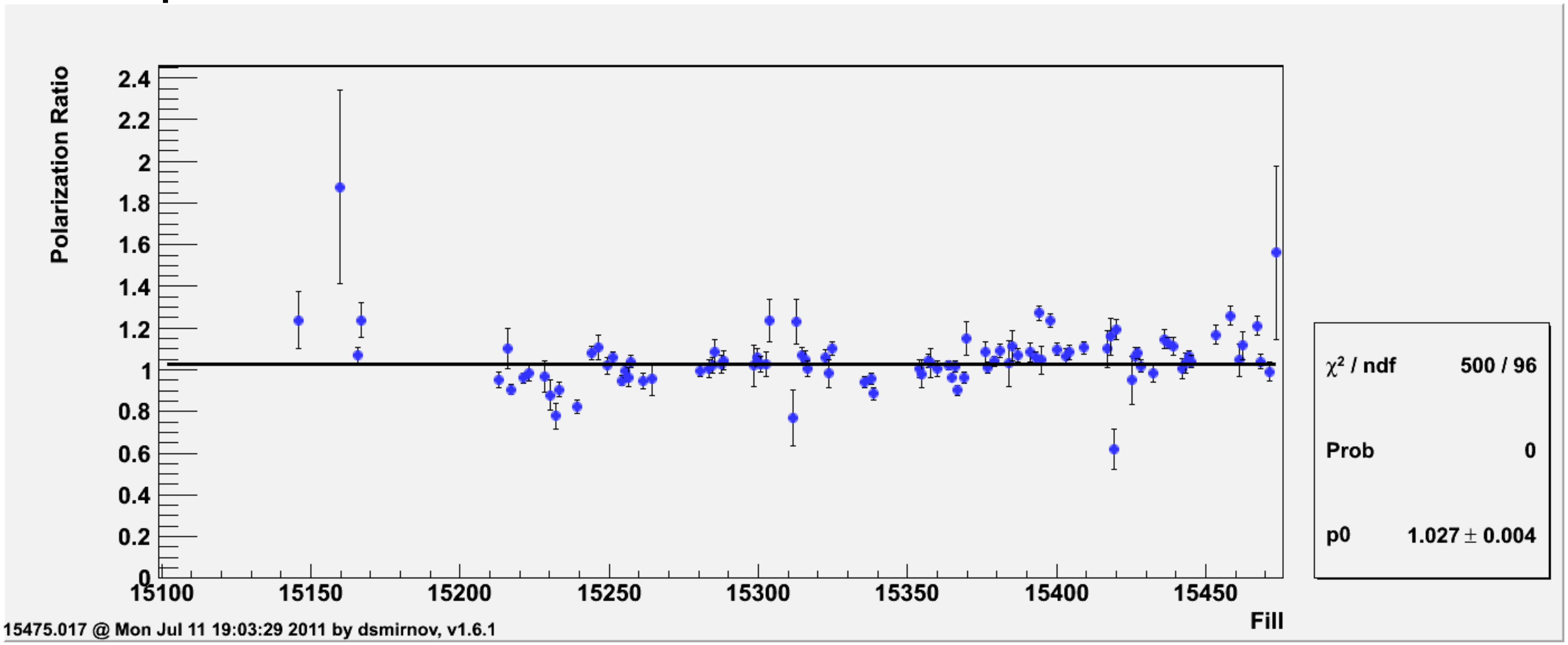
- Check with data: some things should (ideally) be constant
- e.g. pC/H-jet ratio $\Rightarrow A_N$, here per RHIC fill:
- Error bars are stat., dominated by H-jet



- Constant fit, χ^2/NDOF>1 $\Rightarrow$ estimate of syst. uncert.

Syst. checks with data

- Check with data: some things should (ideally) be the same
- Have two pC polar./ring, each measurement same P
- Here ratio per RHIC fill; error bars are stat.:

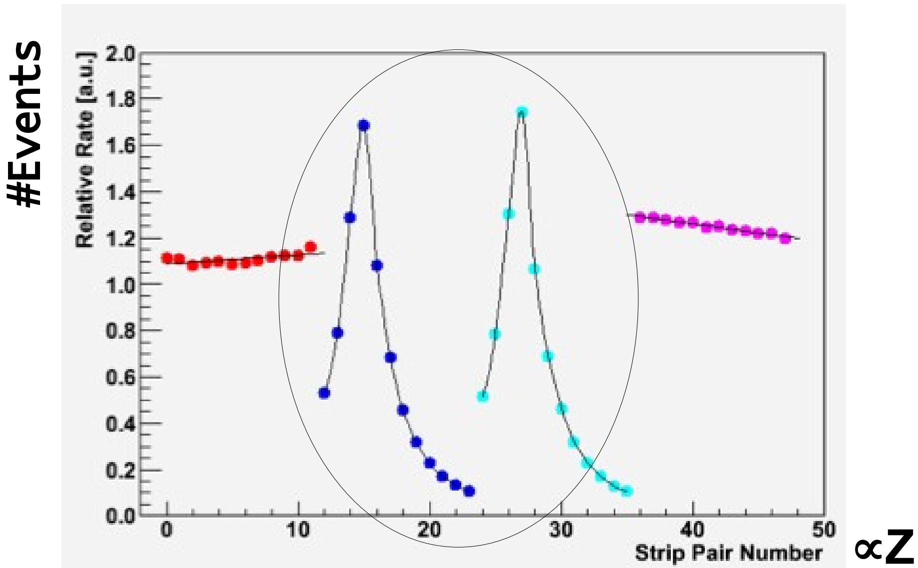


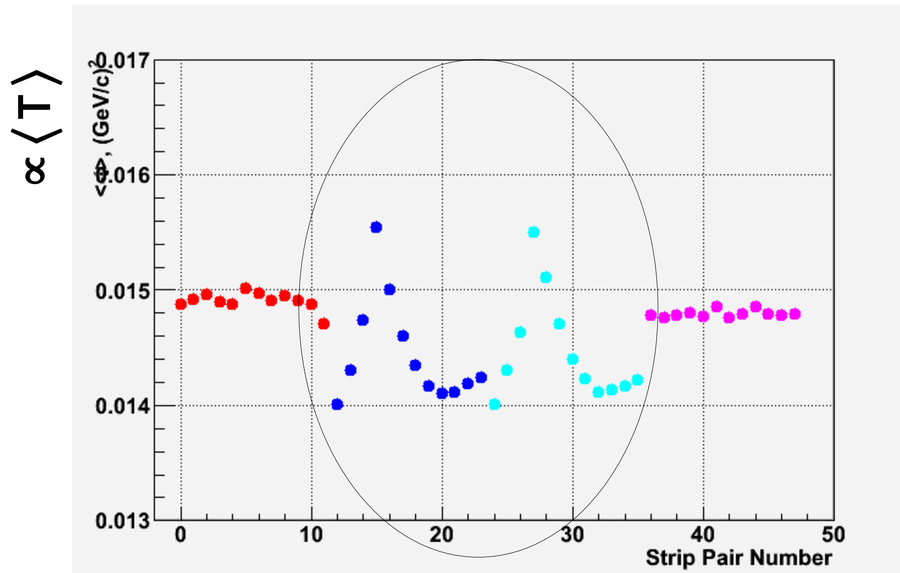
- Constant fit, χ^2/NDOF>1 $\Rightarrow$ estimate of syst. uncert.

- <u>Data like these used to evaluate syst. uncertainties</u>

Improvements: pC det. segment.

- Present: RHIC pC detectors segmented azimuthally
- AGS pC polar. has some longitudinally (Z) segmented detectors:

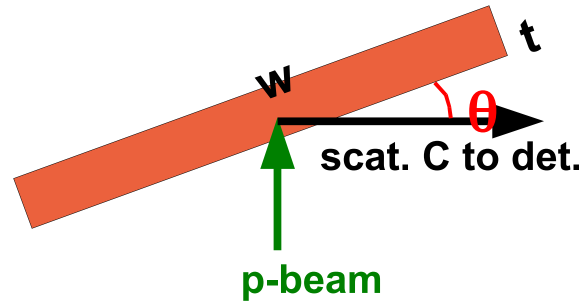


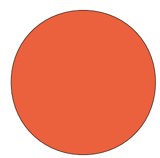
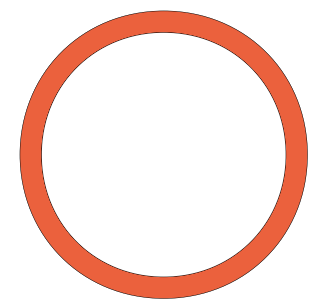


- Peak of distributions ~ Z of target w.r.t. detector
- Widths of these distributions ~ path length in target material (compare plots slide 11)
- May rotate a few RHIC detectors to longitudinal segmentation
- Maybe track Z (swaying ribbons), correlate width↔A_N ⇒ correct for target alignment, orientation

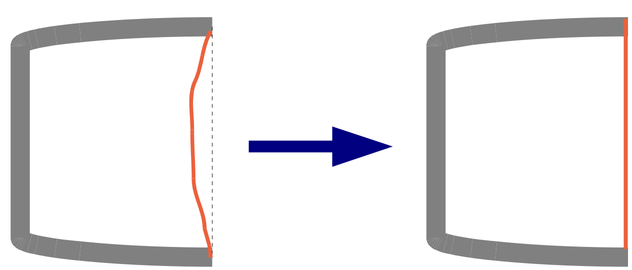
Improvements: targets

<u>Orientation problem:</u>



- Circularly symmetric targets would avoid orientation stability problem
- e.g. carbon wire:  or a carbon tube: 
- Starting to look like nanotubes...
- To set the scale, present 25 nm ribbons ~115 C atoms thick

<u>Looseness problem:</u>



- Tight, straight ribbon would help orientation, alignment stability
- But tradeoff: tightness↔target lifetime

- <u>**Need to explore alternate technologies, geometries...**</u>

Closing

Proton polarimetry

- Targets can give largest systematic effects
- May not be all, but must study, pursue alternatives

^{3}He polarimetry

- H-jet replacement probably very different situation
- pC lessons probably applicable for a ^{3}HeC polarimeter